Applying a Systems Model to Enterprise Risk Management

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Abstract: Enterprise risk management (ERM) has emerged as the new paradigm in risk management with the goal of holistically managing all risks facing an enterprise. Yet organizations still manage risks in a piece-meal fashion and struggle to effectively implement ERM and manage complex strategic risks. This article proposes a solution to this problem: ERM implementation using a system dynamics approach, which enables integrating risks in a causal modeling environment that includes feedback and delays. The methodology is then described using the ISO 31000 Risk Management Standard and illustrated using an example.

Keywords: System Dynamics, Enterprise Risk Management, ISO 31000

EMJ Focus Areas: Operations Management, Organizational and Performance Assessment, Quantitative Methods and Models, Systems Engineering

This article proposes a system dynamics (SD) model for enterprise risk management (ERM). System dynamics modeling appears well-suited to improve ERM implementation. This article provides brief introductions to important topics that are relatively unknown by engineering managers: the ERM philosophy and the ISO 31000 Risk Management Standard, which is being used around the world by organizations to implement ERM.

The Harvard Business Review listed ERM as one of the "breakthrough ideas for 2004", yet even firms with supposedly sophisticated ERM failed during the 2008 financial crisis. ERM is a holistic, new, and evolving risk management approach, but firms attempting to use ERM still mainly follow a reductionist approach, using tools that evolved out of traditional risk management for dealing with insurable and financial risks. Most firms have struggled to deal with the more important operational and strategic risks (Bromiley, McShane, Nair & Rustambekov, 2014). This article proposes that these types of risks are better handled by structural or mechanism-based approaches, such as system dynamics modeling, which is a common construct in the science and engineering fields. The authors did not find previous research that applies a systems approach to ERM. Olson and Wu (2010) apply techniques that are widely used in engineering to risk management, but leave out systems techniques such as system dynamics.

The following provides a general introduction to ERM and the ISO 31000 Risk Management Standard. Next, issues that firms have in realizing the ERM philosophy are discussed, and a role that system dynamics can play in alleviating these problems is proposed. Next, a general description is provided of how to apply the system dynamics approach for modeling an ERM process that uses the ISO 31000 Standard, followed by an illustration of the system dynamics approach for modeling complex strategic and operational risks for a hypothetical pharmaceutical company. Implications for engineering managers are discussed last.

What are Enterprise Risk Management (ERM) and ISO 31000?

ERM and the ISO 31000 Risk Management Standard, which have received substantial attention in other disciplines, are unfamiliar topics for many engineering managers. A main goal of ERM is to holistically manage all risks faced by an enterprise: hazard, financial, operational, and strategic risks (Elliott, 2013). ERM represents a fundamental shift in how firms manage risk with the philosophy of bridging the risk management silos within an enterprise and implementing a firm-wide structure for dealing with the portfolio of risks faced by a firm (McShane, Nair, & Rustambekov, 2011).

Until the 1970s, corporate risk management was a mid-level technical function in a firm that dealt only with hazard risks, which are mainly insurable-type risks related to property, liability, and employee safety exposures. Risk managers at firms in this era were typically insurance experts and buyers. In the 1970s, a new silo of financial risk management arose with the advent of the Black-Scholes option pricing model (BSOPM), which gave rise to the derivatives industry, allowing financial risks to be managed.

Now firms could transfer their hazard risks using insurance and their financial risks using derivatives; however, firms typically managed these risks in silos, with hazard risks managed in one department and financial risks in another with no coordination. Over time, the disadvantages of this traditional silo view of risk management in an increasingly complex and interconnected world became evident, and the evolution toward ERM began in the late 1990s. For a detailed history of the evolution of ERM out of multiple disciplines, see Bromiley, McShane, Nair, and Rustambekov (2014), and Nair, Rustambekov, McShane, and Fainshmidt (2014).

With firms struggling to implement ERM concepts, the Committee of Sponsoring Organizations (COSO) introduced the COSO ERM Framework in 2004. COSO consists mainly of accounting organizations, and the framework is aimed at the internal audit function where control and compliance are paramount. A substantial segment of risk management practitioners did not embrace COSO ERM and worked many years with international standards experts to develop the IS0 31000 Risk Management Standard, which was introduced in 2009 (Gjerdrum & Peter, 2011). ISO 31000 is an internationally-accepted risk management standard that many firms now use to implement ERM (RIMS, 2011). Exhibit 1 shows the ISO 31000 risk management process.

ERM Implementation Problems and a Proposed Role for System Dynamics

Many firms are attempting to implement ERM as the new holistic organizing principle to deal with the full set of risks resulting from a dynamic risk environment characterized by complex issues

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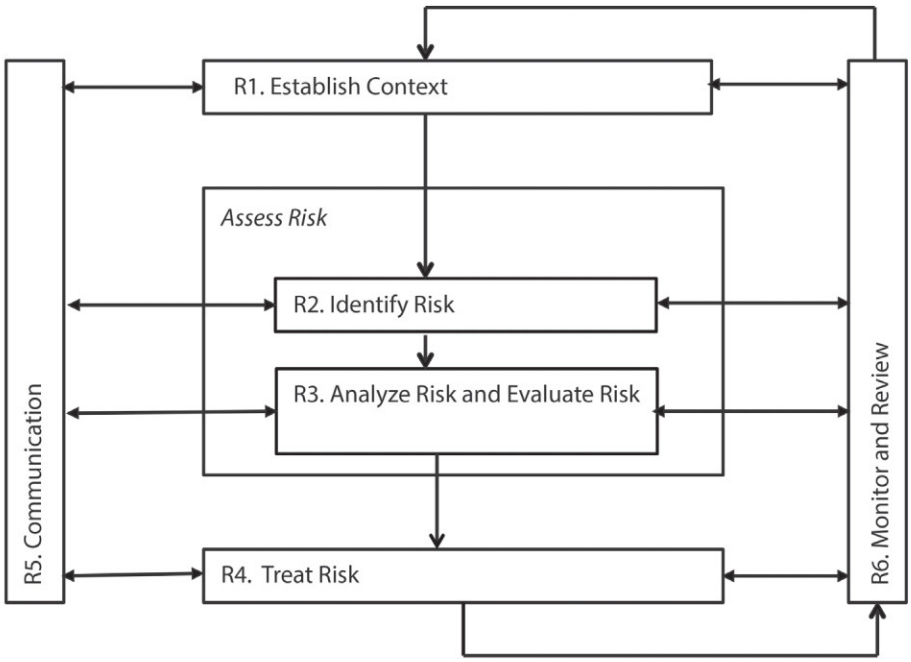
Exhibit 1. Risk Management Process: Based on the ISO 31000 Risk Management Standard



such as rapid changes in information technologies, the explosion of globalization and outsourcing, and increased competition. Firms attempting to implement ERM are struggling to make changes in their risk management philosophy. Organizations have years of experience in dealing with measurable risks, such as insurable and financial risks. These types of risk are relatively easy to measure and manage because substantial historical data is available; however, operational and strategic risks are typically unique to the firm with little or no data available and, thus, difficult to quantify and manage. The common methods used for measuring financial risk, such as Value-at-Risk (VaR), evolved out of options theory and modern portfolio theory. These statistical methods depend on historical data being available, so are not useful for operational and strategic risks. Efforts to integrate the management of risks on an enterprise-wide scale are limited by the inability to model these types of risks.

This article proposes that more complex risks are better handled by structural or mechanism-based approaches, which is a common construct in science and engineering fields. These causal approaches model the components of a system and their relationship. Statistical methods, such as VaR, are parametric methods that do not attempt to understand the underlying mechanisms of the system. Traditionally, statistical models do not aim to provide explanations of mechanisms or causations. System dynamics is a causal modeling approach that evolved out of work on feedback control systems. Owing to system dynamics' ability to handle complex inter-relationships, nonlinearity, and feedback loop structures and time delays (Forrester, 1994), the methodology has found application in the conceptualization and implementation of social system models, for example Gill (1996), including management systems.

Causal models fall under the systems theory umbrella and are useful in understanding the dynamic behavior of complex systems. A main tenet of causal models is that modeling each component individually and aggregating the components is not enough to determine the behavior of a system. In addition, understanding and exploring components such as feedback loops, time delays, and other mechanisms are equally, if not more important. These models can address many of the challenges facing ERM. Current ERM practices lack a process to integrate the diverse risks that arise in an organization. Practitioners attempting to implement ERM use statistical tools from traditional risk management and are struggling to integrate and aggregate risks across silos (Bromiley, McShane, Nair, & Rustambekov, 2014). Integrating multiple risks in a justifiable manner requires looking deeper than just treating risks as a list of items to be addressed. It requires a mechanism-based approach to modeling risk.

System dynamics has its foundation in engineering science and has open-ended flexibility, which can offer significant benefits for ERM. For example, system dynamics permits representing reality at different levels of granularities, allows graphical representation of relationships and mechanisms that users can visualize, allows for information flows; emphasizes structure over narrowly defined coefficient accuracy; enables integration of multiple risks; and uses data from a broad range of sources including domain knowledge, anecdotal evidence, and logical inferences (Forrester, 1975).

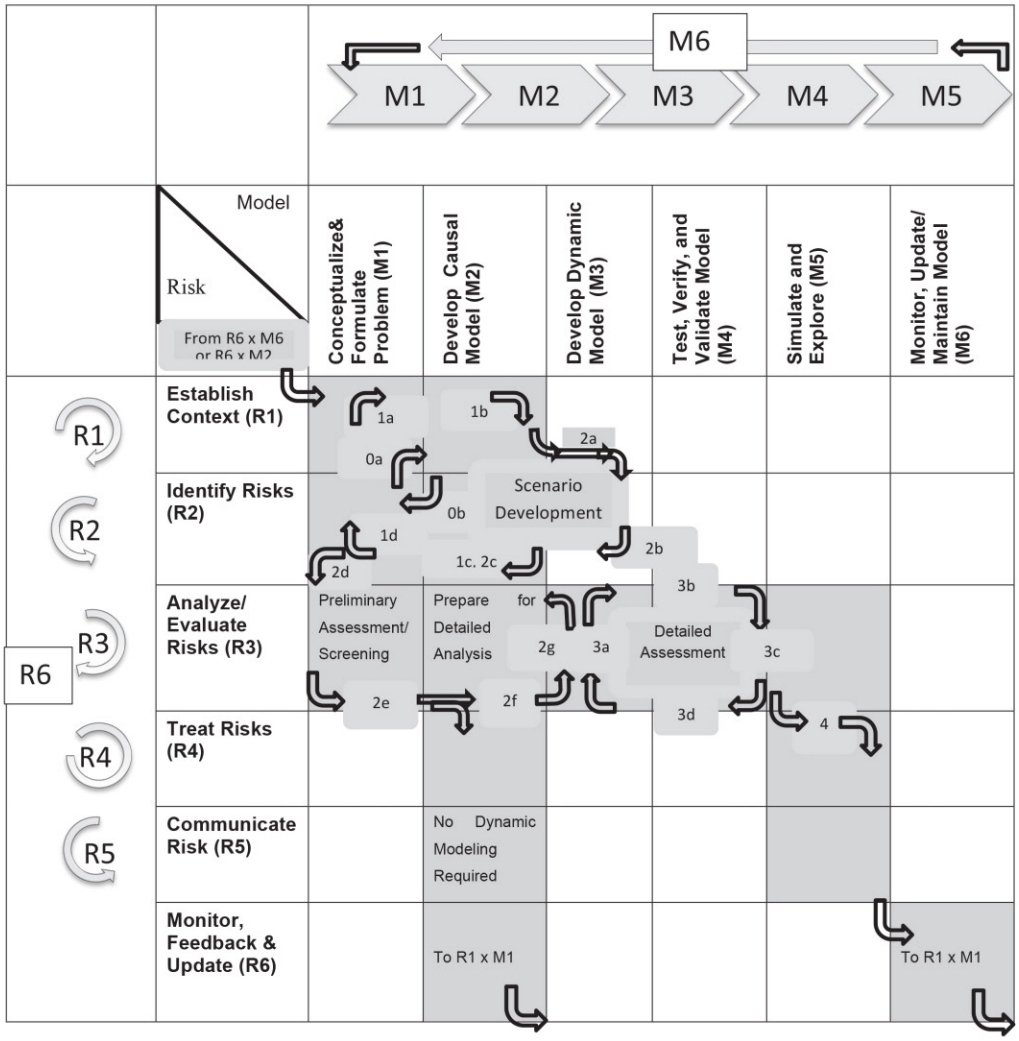
System Dynamics Application to the Enterprise Risk Management Process

In describing the role of system dynamics in risk management, two processes are encountered: risk management (R) and modeling and simulation (M). Their interaction is represented through the shaded cells in Exhibit 2. The processes are iterative, meaning cyclical as indicated by the arrows, and independent, meaning there is no specific relationship between the two processes outside this context. Several short cycles and one long cycle encompass the entire process.

The processes are iterative, but there is a direction of movement (linear flow or sequencing of steps) associated with these processes, resulting in a temporal dependency (R(t, …) and M(t, ..)). The combined process progresses downward close to the diagonal, which means that the diagonal cells in the RxM matrix are generally more populated than other cells; however,

Exhibit 2. Matrix of Interaction between Risk Management and Modeling Processes

Note: Short cycles, 0a-b, 1a-d, 2a-g, 3a-d are shown for illustration. The actual number of iterations will be a function of project objective and requirements, as well as availability of information and resources.



the matrix structure has value beyond this interpretation and is proposed to:

- integrate the otherwise independent processes
- show relationships among steps in both processes (the structure informs which modeling steps are involved when a risk management step is undertaken), and
- show that there are short cycles as well as long cycles.

Our primary motivation in proposing the following approach is to take advantage of the integration, connectedness, and transparency that system dynamics offers to the ISO 31000 Risk Management process. The following describes generally how the system dynamics approach can be applied to the ISO 31000 process. For the meaning of R*X* and M*X*, refer to Exhibit 2.

STEP R1: Establish Context

The modeling process assists with the conceptual stage (R1xM1) of the risk management process, which is termed "establish context" in the ISO 31000 process, and considers external and internal factors that are important in determining the extent of the risk management program and in formulating risk management policy. Risk criteria are established, which are used later to determine the most important identified risks and the extent to treat these risks. The external context includes external stakeholders, the external environment, and anything else that can affect objectives. The internal context includes the organization's capability, culture, and stakeholders, such as employees and the board of directors.

System dynamics is applied at the beginning of the risk management process when context is established. The system is characterized through causal diagrams, and scenarios are developed (R2xM2). When establishing context, information is gathered, the parameters and boundaries of the analysis are set, assumptions are explicated, and a conceptual model of the problem and contexts is developed. System dynamics modeling helps formulate a conceptual model of the system, and requires elicitation of relationships with a sense of extent and direction of influence. The *establish context* step is used to gather information and set the parameters and boundaries of the analysis. The information will be collected through multiple modes, as available, including interview and document review, with the aim of understanding the external environment (including the stakeholders), internal processes, strategies, and risk management context.

STEP R2: Identify Risks

When the risk management process completes R1 and moves into row R2 via the cyclic 0a-b and 1a-d steps, risk identification is carried out. Risk identification involves identifying internal and external events that potentially affect achievement of the objectives. Multiple perspectives need to be considered in identifying risks. Most audit and standard based approaches, which dominate the ERM space today, tend to limit themselves to a single discipline (Letens et al., 2008; Maytorena et al., 2007). Advanced stages of risk identification (such as those relating to feedback and time lag) might even occur during the development of dynamic models.

The objective is to generate an exhaustive list of the risks with potential for disruption. Where necessary, domain experts are interviewed to uncover the social, economic, political, and technological forces at play, recognizing that these forces may interact. From these interviews, significant forces are identified and, through a further survey, key trends and uncertainties that form the pivotal forces that will drive the scenarios are revealed. Using a mix of risk identification techniques (e.g. surveys, individual interviews, workshops, group or individual based HAZOP, and if necessary, preliminary fault-trees and event-trees), information is collected on the system and environment, and the set of risks is established.

STEP R3: Risk Analysis and Evaluation

Preliminary risk assessment and preparation for detailed analysis takes place when the process, following the route 2a-g, is in the cells R3xM1 and R3xM2 after 0a-b, 1a-d have been completed. Significant risks are screened based on an initial, subjective analysis of impact and likelihood. Bahill and Smith (2009) describe and illustrate a balanced, normative guideline for carrying out a semi-quantitative assessment process. Risk factors are then ranked using subjective analysis. The key dimensions of the analysis are the likelihood that the risk will occur (from remote to virtually certain); and the impact if the risk actually occurred (from minor to catastrophic). The output of this exercise is a list of key risks that need to be analyzed and evaluated in detail. Upon completion of preliminary assessment of risk, preparation for detailed analysis (2f) begins. In some cases, one might be required to go back to refine the preliminary assessment (returning loop 2f, 2g). In most cases, the assessment progresses to detailed assessment via 3a-d for one or two cycles, which is when the dynamic model is developed.

STEP R4: Risk Treatment

Risk treatment is the process of deciding on one or more options for modifying a risk, then implementing the treatment. Risk treatment options are categorized as risk avoidance, risk mitigation (likelihood or impact reduction), risk retention, risk transfer/sharing, and risk exploitation. The goal is to treat the risk to the extent that the residual risk complies with the risk criteria of the organization that was determined in the establish context step. Effort must be made in this risk treatment step to understand whether or not the risk treatment used introduces another risk. Once a valid model is achieved, it can be employed to explore the decision space by evaluating existing and hypothetical alternatives (occurring at R4xM5 interaction).

STEP R5: Risk Communication

To ensure that a silo mentality does not develop, communication needs to occur with internal and external stakeholders during all steps of the ERM process. The model-based approach allows use of the model as a tool in dialogue and communication, which supports the R5xM5 interaction.

STEP R6: Monitoring, Feedback, Learning and Update

For both modeling and risk management, monitoring, feedback, and update are essential components. The information from one cycle feeds back into the next cycle. When conducted with the support of a dynamic model, such as system dynamics, the subsequent cycles of risk management are documented and easy to visualize, allowing the capture and maintenance of knowledge and learning from previous cycles. The interactive space of R5xM6 illustrates the convergence in these steps, which feeds back to R1xM1 for the next cycle, as needed. The shaded areas (R4xM2, R5xM2, and R6xM2) illustrate alternative, less rigorous paths. Here, the preliminary assessment is deemed adequate based on the level of risks, as well as the objectives, and no detailed analysis is carried out. Once this decision is made (at 2f), the modeling is concluded with the causal model. The focus shifts to treatment, communication, and monitoring. The level of assessment should be commensurate with the level of risk.

Populating, Testing and Validating the Model

In practice, models must be populated and validated. The data for models come from multiple sources, with a primary source often being subject matter experts. The burden of the developed, integrative modeling process is to systematically transform empirical evidence, tacit knowledge, and expert knowledge from diverse sources into data. The goals are to reduce, if not eliminate, human errors and cognitive biases (for example, confirmation bias); to ensure that uncertainties in input parameters are addressed; and to verify and validate the model as a whole and the knowledge base in particular (Bharathy & Silverman, 2012).

Illustrative Example for Complex Supply Chain Risk

An example for managing a complex risk scenario (supply chain risk associated with product launch) is created for a fictitious pharmaceutical company (Fairy Pharma) which was synthesized based on the authors' experience with multiple organizations. This example illustrates some of the concepts related to the role of system dynamics in the risk management process described.

At Fairy Pharma, the risk universe consists of over 100 risks, including risks faced by most enterprises: (1) governance issues, such as failure in governance, oversight, and audit; (2) strategic issues, such as expected and unexpected changes to competition and demand; (3) operational issues, such as failure to maintain a safe and secure environment; (4) ethical issues, such as misconduct; (5) regulatory issues, such as failure to act in accordance with rules and regulations; (6) human resource related issues, such as inability to recruit and retain talent; (7) organizational, institutional, or cultural issues, such as entrenched siloes and turf wars; (8) financial issues, such as inaccurate or untimely management reporting; and (9) technological issues, such as loss of a data center and key IT systems.

Other risks are specific to the pharmaceutical business model, often pertaining to the industry's blockbuster model in which firms invest huge sums in a few products with firm survival dependent on a few, unusually successful drugs delivering outsized sales and profits. In moving drugs from conception to completion in the blockbuster model, various risks may ultimately lead to financial ruin, compliance violations with huge fines, and/or increased regulatory oversight.

Exhibits 3a and 3b are modified causal diagrams that illustrate, at a high level, the main risks (both generic and Pharma-specific) faced by a pharmaceutical firm. A preliminary conceptual model is developed at the end of step R1 and is instantiated with actual values and used in step R2. The conceptual diagram is represented in a causal diagram with links indicating how various factors influence each other (positively or negatively) to co-create the outcome. The legends (Exhibit 3b) show how the model should be interpreted. Please note that the supply chain risk associated with product launch is marked with a bold circle, signifying its importance.

Exhibit 3a. Enterprise Environment of the Organization (Fairy Pharma example)

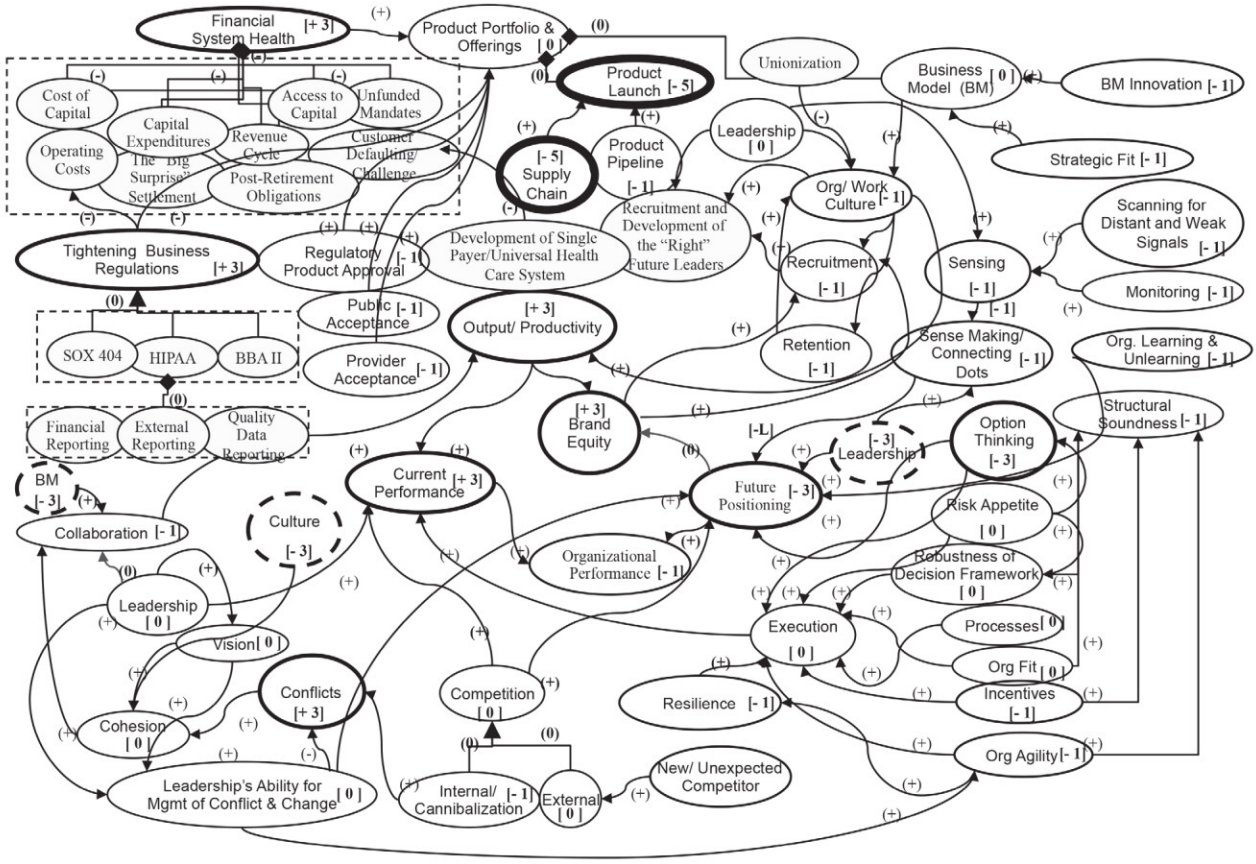
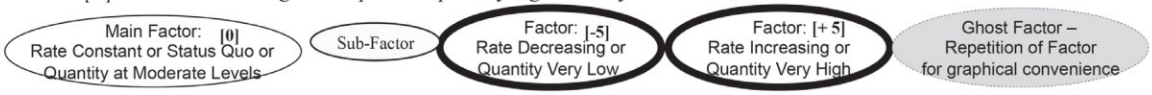


Exhibit 3b. Legends for Exhibit 3a

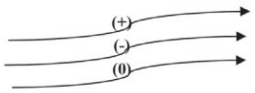
System Status

- [+ 5] Rate increasing at fast pace or quantity significantly higher than "normal"
- [+ 3] Rate increasing at moderate pace or quantity moderately higher than "normal"
- [+ 1] Rate increasing at slow pace or quantity slightly higher than "normal"
- [0] Rate constant or quantity "normal" and status quo prevails
- [- 1] Rate decreasing at slow pace or quantity slightly lower than "normal"
- [- 3] Rate decreasing at moderate pace or quantity moderately lower than "normal"
- [- 5] Rate decreasing at fast pace or quantity significantly lower than "normal"



Thickness of the border indicates current level, thicker implying higher value relative to "normal" enterprise.

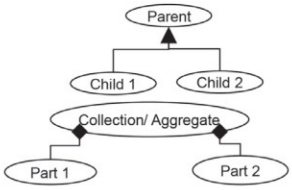
Relationships/ Interactions



Exerts Positive Influence (influence is in the same direction as the factor)

Exerts Negative Influence (influence is in the opposite direction as the factor)

Exerts Neutral/ Mixed/ Uncertainties Influence



Inheritance/ Is-A Relationship (e.g. Parents-Children, Template-Copies)
Specific cases out of the Same Template

Aggregate / Parts Relationship (e.g. Car and Parts such as Engine, Radiator)

In system dynamics, a causal link is ascribed between two variables when the modeler believes that what happens in an "independent variable" will cause some consequence in a "dependent variable." The polarities denote the direction of influence. This is necessary to convert disparate concepts about the enterprise into what can be analyzed through behavior. While a causal model is an explicit representation of the mental model, it is not constructed in an unstructured way. In a modeling project, the factors typically come from a combination of literature review, interviews both internal and external to the organization, observation of the phenomenon, workshops, and a modeler's judgment. In the Fairy Pharma case, the model is a synthesis of the authors' knowledge of the industry (and not any particular company), and, therefore, is derived from the authors' understanding of the problem.

In any risk management exercise, the most significant step, and often the most difficult step, is the identification of risk factors. The authors employed multiple sources of data to construct the conceptual causal loop diagram and identify the risk factors. Preliminary screening of identified risks was completed, and for risks that were significant, further drill down into the causal model was completed. As a model-based approach to ERM, the goal is to understand risks, as much as to rate risks. Drilling down and assessing detailed risks involved constructing causal loop diagrams of the sub-system, namely the pharmaceutical supply chain with particular emphasis on product launch and commercialization.

To clarify how the factors and relationships among factors were determined, the authors compiled a series of conceptual models. These models were used as a prompt for gathering data and carrying out assessments. The pharmaceutical supply chain goes through a number of well-defined stages during the lifecycle of a blockbuster drug (Pedrosoa & Nakanob, 2009). Based on input from a literature review (e.g., Enyinda, 2009; Enyinda et al., 2010; Pedrosoa & Nakanob, 2009; Health Strategies Consultancy 2005), supplemented by subject matter experts, factors that could affect this pharmaceutical supply chain were identified. In the system dynamics tradition, we reviewed, compiled, and integrated this information, and then developed a conceptual model.

The same information is exploited in the subsequent risk identification stage when the conceptual models are used as an anchoring framework to: a) traverse through the system and ask what-if questions, b) develop questionnaires for interviews and surveys, and c) synthesize knowledge elicitation results. Conceptual models can be expressed in many forms including various standard diagrams such as causal loop diagrams. In essence, using conceptual and causal loop diagrams, we carried out the equivalent of a HAZOP study, whereby key assumptions and givens that when violated could result in the failure of the system are identified.

Salient characteristics that distinguish pharmaceutical product-to-market supply chains from other supply chains include: (1) low likelihood of success during product development, high investment costs, all-or-nothing blockbuster model; (2) high uncertainty in the outcome and hence the need for a portfolio approach (we have simplified to a single drug for the sake of illustration); (3) heavy investment in R&D, marketing, assurance of quality, and safety; (4) intense regulatory control; (5) low cost of goods sold in comparison to the selling price, and hence usage of buffer inventory to provide assurance of availability; (6) predominance of intellectual and relationship assets compared to typical industrial supply chains; and (7) involvement of multiple players in the prescription and use of drugs (Northrup, 2005; Cockburn, 2004).

According to Burns et al. (2002), the key stakeholders in the value chain are identified as: purchasers, fiscal intermediaries such as insurers including Medicare/ Medicaid, providers, and product intermediaries, such as wholesalers, retailers, and producers. The complexity and problem pertaining to healthcare value chains are structurally unique in that payer (insurance companies including government), payee (Pharma), prescriber (provider), and end-user/consumer (patient) are separate entities in the healthcare drug decisions. Healthcare is also highly regulated. This results in interesting dynamics with increased complexity (Porter & Teisberg, 2006). Additionally, the end-user (patient) does not typically fully understand the healthcare delivery system. The supply network itself is aimed at balancing the service level, cost, flexibility, and risk. One of the constraints on pharmaceutical supply chains is the time lag. Any change to the supply chain has to be designed (and preferably implemented) well before the launch of the drug. In addition, much of the pharmaceutical value chain is tied to intangible infrastructure (Northrup, 2005; Bradley & Weber, 2004; Pedrosoa & Nakanob, 2009).

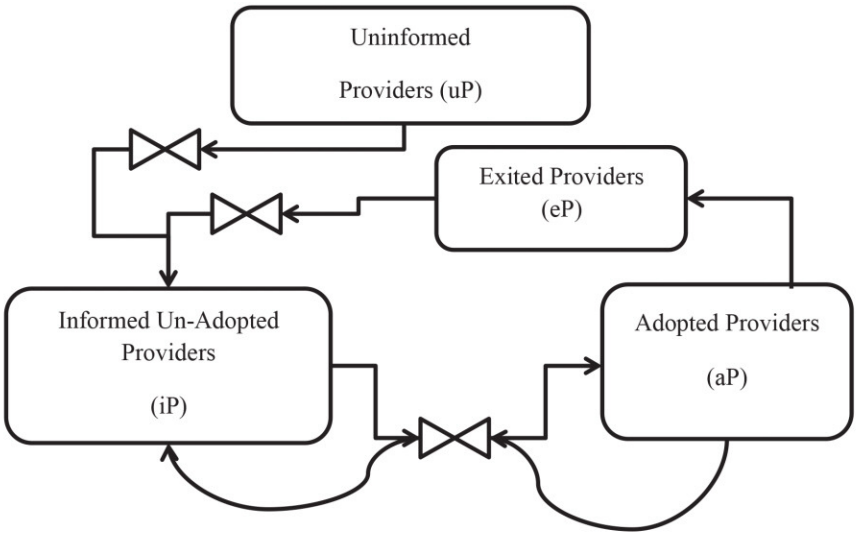
In terms of the supply chain for commercialization and launching, communicating to the consumer occurs in multiple modes. There are legal constraints about the nature of messages directed at consumers and indications that direct consumer messaging has limited effectiveness. Academic details directed at providers is not only a more scientific and rational approach, but more effective (Soumerai & Avorn, 1990). In our design, we assume that academic details combined with generic marketing to providers will be carried out. We also assume low profile, direct marketing to consumers, ignoring regional regulatory variations (Azoulay, 2002).

System dynamics allows modeling of two aspects of drug adoption that are worth mentioning: feedback and delays – capturing temporal delays (time lags) that are important to the success of the supply chain (Lee et al., 1997). For the sake of brevity, this section illustrates only the feedback aspect of the supply chain. This segment of the system dynamics model illustrates adoption of the drug by providers, which means doctors in this example. Adoption of the drug is modeled through the Bass Diffusion Model (Sterman, 2000; Maani & Cavana, 2007), centered on work introduced by Bass (1969), and subsequently extended by Norton and Bass (1987). While the Bass model has several weaknesses (see Russell, 1980), we found that it would suffice for our purpose. Unlike the traditional model, which assesses the diffusion in a market among consumers, in this model, providers are the major influence. The adoption model with related feedback is simplified for the sake of illustration and shown in Exhibit 4.

Causal loops show the relationships among the factors, including the direction of influence; however, this is a static view. In order to obtain a dynamic view, we use stocks and flows, which can generate functional relationships over time. For example, inflow rate minus the outflow rate gives the rate of accumulation of the stock in a time step. Integration of differential flows over the period of interest (through simulation) gives the level of the stock. In effect, the combination of stocks and flows represents a system of integral or differential equations. Structurally, a significant part of this model is that there is feedback related to the rate of change of providers adopting the drug. In the following, we use the term "adopted providers" to mean providers that have adopted the drug. The rate of change of the adopted provider population is given by:

$$[\text{Adopted Providers}(t) - \text{Adopted Providers}(t - dt)]/dt = \text{Adoption Rate} - \text{Exit Rate} \quad (1)$$

Exhibit 4. System Dynamics Map for Product Adoption (The adoption dynamics model is a modified version of the Bass Diffusion Model (Sterman, 2000; Maani and Cavana, 2007))



Adoption rate is the rate at which providers are adopting the drug, and exit rate is the rate at which providers, who had adopted the drug, have stopped prescribing the drug. Several sources of information influence the adoption rate: Healthcare providers respond to multiple sources of information in deciding whether or not to adopt the drug, such as technical information from authoritative sources and peers, social information from peers, and sales information from representatives. Healthcare providers' considerations in the adoption decision include efficacy, safety, hospital logistics and support, price, reimbursement, and regulatory signals. Consumers (patients) also receive messages and can request (or persuade) the provider to adopt the drug. The sources of information that affect the adoption rate are given by the following equation:

$$\begin{aligned}\text{Adoption Rate} = {} & (\text{Adoption\_from\_Authoritative\_Sources [afas]} + \\ & \text{Adoption\_from\_Advertising [afad]} + \\ & \text{Adoption\_from\_Social\_Sources [afss]} + \\ & \text{Adoption\_Encouraged\_by\_Patients [aepn]})\end{aligned} \quad (2)$$

Exhibit 4 shows the feedback that can occur among the various categories of adoptors where aP are the adopted providers (providers who have already adopted the drug), eP are the exited providers (providers who had adopted the drug but no longer do so), uP are the uninformed providers (who do not have any information about the drug), and iP are the informed un-adopted providers (who have information about the drug but have not adopted it). The adoption rate is a function of the available pool of potential adopters, especially the informed un-adopted providers (iP). A simple two loop version for the rate of change of adopted providers (aP) and informed un-adopted providers (iP) can be described as follows:

$$d[aP]/dt = \Omega(iP, \ldots.) - \lambda(eP, \ldots.) \quad (3)$$

$$d[iP]/dt = \Phi\,(uP, \ldots.) + \Psi(eP, \ldots.) - \Theta(aP, ..) \quad (4)$$

…where Ω, λ, Φ, Ψ, Θ are functions. In the simplest cases, they could be constants (such as fractions), but, in reality, incorporate various factors affecting the respective rates and could be generalized as (non-linear) polynomials. Exhibit 4 and Equations 2-4 show that positive and negative feedback loops are present with iP being positively dependent on uP and negatively on aP. Dependence of iP on eP is more complicated: exited providers may be spreading negative messages but are also available for future recruitment. Once adopted, actual prescription and consumption occur at the next level. Healthcare providers make prescriptions, but patients consume. The prescription rate depends on the pool of patients seeing an adopted provider. The number of patients who are visiting providers is a function of total unhealthy population. In these models, feedback is used from the perspective of both engineered and social systems. In social systems, feedback is used for regulation, interpretation, integration, and differentiation, and contributes to systems design. In engineering systems, the concept of feedback is usually related to control and design. Some feedback loops (and several factors) are involved in the process of conversion of uP to iP and then iP to aP.

We summarize the salient feedback loops as follows: Healthcare providers, who are informed by either advertisement or through social means, would prescribe the drugs if they find that the efficacy and safety of the drug is satisfactory. Any perceived risks such as regulatory intervention/restriction might significantly and negatively influence consumption and adoption. Likewise, hospital preferences will also directly influence the adoption by providers. The drug's perceived performance, and its adoption, are considered in comparison to competing drugs. Any new drug has to out-perform its current competition or other substitutes. Another consideration that would influence the decision is how well the reimbursement process works, which is mainly determined by the payers (insurers/patients). For the reimbursement process, the cost and efficacy, and, to some extent, safety, of a drug are considerations in having claims approved. Once the reimbursement process is established and flows without major impediments, the prescription rate will be positively influenced by the reimbursement process. At the same time, increasing prescription rates by providers will also positively influence the reimbursement process. A counterbalance to an increasing rate of adoption is saturation. Initially, the adoption rate will increase due to positive feedback, but will decrease as the pool of uninformed providers decrease. The pharmaceutical

company may determine the price based on factors such as supply and demand considerations, regulatory limits, cost of producing the pipeline, and the profile of return on investment while the patent lasts. One external influence on the price is the willingness of the market to pay.

In this summary case, we have highlighted some salient aspects and benefits of applying system dynamics to a complex risk scenario, but this is the tip of the iceberg. Among the benefits of undertaking such an exercise are development of a dynamic model as a decision support tool, as well as the immersion and systematic analysis that would come from the exercise.

Implications for Engineering Managers

The important contribution of this article is a description of a system dynamics (SD) approach for enterprise risk management (ERM). System dynamic approaches have rarely been applied in a risk management context. The implications of the topics covered in this article for engineering managers are many. For example, engineering managers typically are still using approaches and tools that were developed for traditional silo-based risk management. Engineering managers can use the causal modeling methodology introduced in this article to help break down silos. A systems-based, transparent, dynamic modeling framework assists with understanding concepts and manifestations of cause, effect, risk, and other system level relationships that are otherwise difficult to grasp (Bharathy & Silverman, 2012).

If the move toward a broad, holistic risk management process is beyond what is currently possible, engineering managers can also apply specific steps described in this article to achieve more narrow goals. For example, engineering managers can apply systems dynamics-based models just to risk identification as described in Step 2: Identify Risks. The discipline of going through modeling exercises provides an opportunity to identify risks in an integrated fashion and in ways that cannot be achieved by other methods (Orlikowski, 2000; Reckwitz, 2002; Schatzki, 2001).

Most ERM practitioners come from accounting, finance, and insurance backgrounds, with little participation from engineering managers. Regardless of the details of the technology, engineering managers should consider investing time and effort to understand and model enterprise risk as described in this article. They should make the traditional gate keepers of ERM aware of what they can bring to table. Incumbents in any field resist the entry of new stakeholders, but efforts by engineering managers to enter the fray will pay off. The engineering profession and tools that engineers are familiar with are necessary to realize the full potential of the ERM philosophy, but engineering managers must first demonstrate initiative and get involved in this conversation.

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